M.R.P. 933
S.C. 11/196
1st September, 1955

Investigations relating to cirrus cloud

by

D. G. James
(Meteorological Office)

METEOROLOGICAL
OFFICE
- 8 FEB 1956
LERWICK OBSERVATORY
SHETLAND

AIR MINISTRY
METEOROLOGICAL RESEARCH COMMITTEE

At the time of issue this report has not been published. Any author desiring to quote this paper should refer to it as "A paper of the Meteorological Research Committee (London), M.R.P. No. 933 by Dr. D.G. James. A copy is available in the Library of the Meteorological Office."

M.R.P. 933
S.C.II/196
1st September, 1955

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

Investigations relating to cirrus cloud

by
D. G. James (Meteorological Office)

1. Introduction

This paper analyses observations of cirrus cloud which were made from aircraft between August, 1952 and December, 1954. In the main, the observations were obtained from aircraft based at West Raynham and at Wyton, the aircraft being on routine navigation flights over the British Isles. Reports were also obtained from aircraft of the Meteorological Research Flight based at Farnborough and were made during their routine high level ascents. It was hoped that any ascent to cirrus levels by aircraft from these stations would yield a report of "Cirrus observed" or "No Cirrus observed", but in the early stages of the investigation a certain reluctance was shown to make a report of the latter type.

In order to facilitate simple analysis of the reports, the reporting stations were issued with proformae which were so designed that an observer was only required to tick whether cirrus cloud had been observed, and if so to give the distribution and type of the cloud, and the heights and temperatures of bases and tops. Amplifying remarks were also invited.

Altogether about 220 reports for 180 separate days were available for analysis by January, 1955. The majority of these cases were reports of the presence or absence of cirrus cloud at a particular place, though several were reports made on long distance navigation flights, sometimes as far as North Africa. There were approximately twice as many reports of "Cirrus observed" as "No Cirrus observed", but it was thought that sufficient observations had been obtained to permit a statistical examination of the reports.

Although a request was made that visibility in and through cirrus cloud should be reported, very few such estimates were made, and no statistical analysis was possible.

2. Analysis of observations

Murgatroyd and Goldsmith (1953) made an analysis of cirrus cloud observations obtained from routine high level ascents by aircraft of the Meteorological Research Flight, and also from several selected synoptic reporting stations. With the greater number of observations available for the present investigation, it was thought worth while repeating some of the histograms presented in the earlier paper.

Fig. 1 shows the distribution of observations of the tops of cirrus cloud relative to the tropopause. It can be seen that a maximum occurs between 2,000 ft. and 3,000 ft. below the tropopause, and that rather more than 50% of the observations of cirrus tops occur from the tropopause down to 6,000 ft. below whilst 29 observations were made of cloud in the stratosphere. Of these latter, 10 were more than 6,000 ft. above the tropopause, the greatest reported height (estimated) being 20,000 ft. above. The occurrence of a maximum just below the tropopause is consistent with the results presented by Murgatroyd and Goldsmith, although a peak of more than 50% was found by those authors to be from 0 to 2,000 ft. below the tropopause.

/Fig. 2

Fig. 2 presents a histogram of the frequency distribution of the depths of bases of the cirrus clouds below the tropopause. No well-marked peak is evident, but more than 50% of the observations give a cloud base between 4,000 ft. and 12,000 ft. below the tropopause.

The frequency distribution of the heights of cirrus cloud bases is shown in Fig. 3, where maxima are evident at about 20,000 ft., 25,000 ft. and 30,000 ft. It was thought that these maxima may well be due to a preference for estimating and reporting heights to the nearest 5,000 ft., though a maximum was also obtained by Murgatroyd and Goldsmith between 25,000 and 30,000 ft. Ten cases were reported when the base of the observed cirrus was above 40,000 ft.

Fig. 4 presents the frequency distribution of the thicknesses of cirrus cloud. About 70% of the cirrus reported had thicknesses in the range from a few hundred feet to 6,000 ft., though thicknesses of up to 17,000 ft. were reported.

3. Analysis of surface charts

It is well known that cirrus cloud is frequently observed in association with a frontal boundary between air masses. However, it is equally apparent from analysis of surface synoptic charts that extensive cirrus cloud is observed in situations other than those exhibiting surface frontal features.

Table 1 presents the frequency distribution of distances of reports of "Cirrus" and "No Cirrus" from surface fronts. It is seen that more than a half of the cirrus reports lie up to 400 mi. ahead of a front and that about a third of the reports lie up to 200 mi. ahead of a front. For observations of "No Cirrus", less than a tenth of the reports lie up to 200 mi. ahead of a front. 38 reports of "Cirrus" and 33 reports of "No Cirrus" were more than 600 mi. distant from any well-marked front.

Table 2 shows the distribution of distances of certain surface pressure features from points of observation of "Cirrus" or "No Cirrus". It will be seen that rather more than half of the "No Cirrus" reports occurred in association with a surface ridge or high cell, while only about 1/3rd of the "Cirrus" reports were found in this region. This table is consistent with Table 1 where a maximum of "Cirrus" reports appear in the region up to 600 mi. ahead of a surface front.

Although Tables 1 and 2 serve to illustrate that the greater part of cirrus cloud reports were made in association with frontal boundaries and with surface troughs, this is already common knowledge among forecasters, and makes no additional contribution to the cirrus forecasting problem.

4. Analysis of upper air soundings

The occurrence of cirrus cloud is undoubtedly associated with moist air in the upper troposphere. Since humidity observations are not normally available at these heights, an examination was made of the dew point depressions at 500, 450 and 400 mb. in the hope that a significant increase in humidity might be apparent below the usual cirrus levels. Table 3 presents the mean depressions of the dew point at 500, 450 and 400 mb. and the significance levels of the differences between the means for occasions of "Cirrus" and "No Cirrus". It can be seen that at all three levels the differences between the means of dew point depression are highly significant.

An analysis was made of cases when the depressions of dew points below temperatures were simultaneously lower at all three levels than the mean depressions for "Cirrus" reports at these levels, and also when the depressions were simultaneously greater at all three levels than the means obtained for "No Cirrus" reports. This included rather more than half of the total cases.

/The

The results are presented in Table 4, from which it is seen that if these criteria had been used as a basis for forecasting, the "useful effort", (Crossley, 1954) and forecast accuracy for forecasts of cirrus cloud would have been 84% and 80% respectively.

This would undoubtedly be of some assistance to a forecaster is assessing the distribution of cirrus cloud from radio-sonde observations.

Kimachi, (1952), suggests that cirrus cloud over Japan is observed only when the 500 mb. temperature falls within discrete limits and has a maximum frequency of occurrence between temperatures from 0°F and -20°F. Analysis of observations in the present investigation showed that the temperatures at 500 mb. when cirrus cloud is reported range from 20°F to -30°F with a flat maximum between +10°F and -15°F. Furthermore, no significant difference was found between the distributions of 500 mb. temperatures for reports of "Cirrus" and "No Cirrus".

Kimachi also suggests that the lapse rate of temperature with height may well be important in the cirrus forecasting problem. This is consistent with the work of Bannon, Frith and Shellard (1951) who obtained a correlation coefficient of 0.80 between the temperature at 500 mb. and the frost point at 300 mb. as measured from aircraft of the Meteorological Research Flight engaged on high level ascents. Table 5 presents the means of the temperature lapse rates at 100 mb. intervals from 500 mb. at times of reports of "Cirrus" and "No Cirrus". The means at each interval are not significantly different, and are of little use for assessing the presence or absence of cirrus cloud.

Murgatroyd and Goldsmith suggest that cirrus cloud is more frequent when the wind at 300 mb. is in the southwest to west sector and least when the wind is in the northeast to east sector. No significant differences were found between the means of the wind strengths at any level up to 200 mb. for reports of "Cirrus" and "No Cirrus". Table 6 presents the frequencies of the winds in various sectors at levels from 500 mb. to 200 mb. for observations of "Cirrus" and "No Cirrus". Considerable variation is observed in the distribution of the winds for these two classes of reports at all levels up to 200 mb., and application of the χ^2 test indicates that the differences are most significant at 400 mb. It can be seen that the large values of χ^2 at most levels result from an excess of "No Cirrus" reports in the E-S sector and an excess of "Cirrus" reports in SW-W sector. These results are in good agreement with those of Murgatroyd and Goldsmith.

It has further been suggested by these authors that warm air advection at cirrus levels is frequently observed when cirrus cloud is reported. This is supported by a report issued by the Washington Air Weather Service, where it is claimed that warm air advection between 700 mb. and 300 mb. may be used as a parameter for forecasting cirrus cloud. Table 7 presents frequencies with which warm or cold air advection are found at times of reports of "Cirrus" and "No Cirrus" at intervals from 500 mb. These frequencies were obtained by examining the winds reported from routine upper air soundings at the times and in the neighbourhoods of the reports. A veering wind with height was taken to indicate warm air advection between the two levels considered and vice versa. In numerous cases the change in direction was slight within the height interval, and all instances where this change was less than 5° were classified as "Neither". Also under this classification were reports of wind strengths less than 5 kt. The distributions of frequencies in these classes were significantly different for reports of "Cirrus" and "No Cirrus" at the 0.1% level or better for all intervals considered except 500-400 mb. Reports of clouds in the stratosphere were not included in these analyses. The association between the occurrence of cirrus cloud and warm air advection in the upper troposphere is thus confirmed.

5. Analysis of 1000-500 mb. thickness charts

Although time differences of up to six hours occurred between the times of observation and the times of the thickness chart used in this analysis, for the purpose of comparison with the thickness charts it was thought justifiable to

neglect the changes in the thermal pattern in this interval. In fact, most of the reports were made on afternoon flights and the average time interval was probably of the order of 1 to 2 hours.

No significant difference was found between the means of the thickness values for the two classes "Cirrus observed" and "No Cirrus observed", though significant differences were evident in the means of the thickness gradients. This is shown in Table 8, where the means of the thermal winds are given for cases of "Cirrus" and "No Cirrus". The means are 21 kt. and 16 kt. respectively, and application of "Student's 't'" test indicates that they are significantly different at the 0.5% level.

An attempt was made to relate the point from which an observation was made to a trough - ridge pattern in the 1000 - 500 mb. thickness field. To allow simple classification, an idealised wavelength was divided into six equal parts along its axis, and the frequencies obtained for each class of reports of "Cirrus" or "No Cirrus". Only about half of the observations allowed of a reasonable degree of confidence in this classification. Fig. 5 presents the ratios of the percentages of the frequency of observations of "Cirrus" to "No Cirrus" in each section of the ideal wavelength. It is clear that this ratio is greatest in and near a thermal ridge and least near a thermal trough, and is consistent with surface observations of the association of cirrus clouds with warm fronts.

Since only about half of the observations were used in the above analysis, an attempt was made to classify types of thickness pattern over the area from which reports were obtained, in terms of the curvature of the thickness lines. The thickness patterns were labelled as cyclonic or anticyclonic according to the sign of the curvature of the thickness lines. If these were straight, or the gradients very weak, the observation was assumed to belong to a third class, neither cyclonic nor anticyclonic. Table 9 presents the frequencies of these observations in these three classes. A χ^2 test applied to the distributions showed that they were significantly different at a level which was better than 0.1%, and the individual χ^2 values indicate that there is a tendency for cirrus cloud to be most frequent when the curvature of the isotherms is anticyclonic.

6. Cirrus cloud and vorticity advection at 300 mb.

French and Johannessen (1953) attempted to relate the presence of extensive layers of cirrus cloud to patterns on the 300 mb. contour chart. For their analysis observations were obtained from high flying aircraft engaged in routine navigation flights over extensive areas of the United States. Their observations were classified according to the sign of the advection of cyclonic vorticity at 300 mb.

Theoretical considerations indicated that if the vertical motion at the tropopause was zero or very small compared with the vertical motions at lower levels then the sign of the vorticity advection at 300 mb. gave the direction of the mean vertical motion through a layer which had its top at the tropopause and its base somewhere below 300 mb.

The authors found that 86% of the mileage flown through extensive cirrus by the aircraft corresponded with a positive sign of the vorticity advection at 300 mb. at the same time, implying on the above assumption upward vertical motion at 300 mb. Further, cirrus cloud sheets were always to be found when the absolute vorticity at 300 mb. was negative.

Using a finite difference approximation to the geostrophic wind it is possible to express the vorticity and also the advection of vorticity at a point in terms of (1) known contour heights at a set of points on a grid centred on the given point, (2) the Coriolis parameter and (3) the magnification factor of the grid. Although the preparation of vorticity

/and

and vorticity advection charts is possible by hand computation, with a large number of cases considerable time and labour is saved by using an electronic computer.

A grid of 12 by 11 points was adopted covering an area bounded approximately by longitudes 40°N and 60°N and latitudes 15°E and 35°W. To conform with the limited capacity of the machine - the M E G computer at Manchester University was used - mean values along a line of latitude of the Coriolis parameter and the magnification factor of the grid were used. These were shown to be justifiable approximations by comparison of several charts analysed fully by hand with and without these limitations. A total of 180 charts was subjected to analysis by the computer, and the field of vorticity advection at 300 mb. obtained for the times of the charts. The distribution of absolute vorticity at the same level was also evaluated for some 40 charts.

Sixteen charts were analysed for occasions when the reporting aircraft were engaged on long distance flights generally at altitudes in excess of 40,000 ft. On two of these flights the cirrus cloud was reported as being well above the aircraft and consequently well into the lower stratosphere. These were not included in the statistical analysis at this stage.

Considering first these observations made during long distance flights, points were taken every 100 mi. of the aircraft track and Table 10 presents the frequencies of the sign of the vorticity advection at 300 mb. for cases of "Cirrus" and "No Cirrus". The cirrus observations have been further divided into two classes, namely thick and patchy. The former includes all observations of cloud sheets thicker than 1,000 ft., whilst the latter includes all observations of wisps, bands and tufts, generally believed to be 3-6 eighths. Reports of anvil cirrus alone were not included. Table 10 shows that 77% of all thick cirrus cloud reported on long range flights were in areas where the vorticity advection at 300 mb. was positive, indicating upward vertical motion in the upper troposphere.

Table 11 presents corresponding figures obtained from the remaining 164 cases, viz., point observations, the cases of cirrus cloud in the stratosphere again being excluded. Several observations were made independently on individual days, and all have been included in Table 11.

Table 12 is obtained by combining Tables 10 and 11, i.e. assuming that an observation every 100 mi. of aircraft track is equivalent to a spot observation. Thus 76% of the observations of thick cirrus cloud were found in areas where the advection of cyclonic vorticity at 300 mb. was positive, whilst 66% of the cases of "No Cirrus" were found in areas where the term was negative.

Little significant difference was found between the means of the absolute vorticities for the two classes "Cirrus" and "No Cirrus", although the number of cases available for analysis was not sufficient to give any statistical accuracy. French and Johannessen state that extensive sheets of cirrus cloud were found in areas where the absolute vorticity at 300 mb. is negative. Since this implies dynamical instability at 300 mb., a phenomenon which is thought to be rare, and in any case confined to small areas only, it is not surprising that no cases were found in the charts analysed when the absolute vorticity was negative. Hence no additional evidence is available for comparison with the claims of the above authors.

7. Analysis of 300 mb. contour charts

Sawyer and Illett (1951) described an investigation into the frequency distribution of type and amount of cirrus cloud in relation to the jet stream at 300 mb. Later, Murray (1953) in an analysis of flights through jet streams made by aircraft of the Meteorological Research Flight drew similar conclusions concerning the distribution

of high and medium layer cloud with respect to the jet stream. Fig. 6(a) shows the frequency distribution of cirrus reports of the present series with distance from the jet stream axis at 300 mb. In spite of the difficulty in placing the jet axis to within ± 100 mi. it is clearly seen that the majority of cirrus reports lie on the high pressure side of the axis, very few being more than 200 mi. on the low pressure side. The division of reports of "No Cirrus" shown at 5(b) is not so well marked, but even so about 2/3 of the reports occur on the low pressure side. These figures show good agreement with the conclusions of the above authors, although many reports of "Cirrus" or "No Cirrus" were rejected as having no apparent association with a jet stream at 300 mb.

It has been shown in Section 6 that there is a significant connection between the presence of cirrus cloud in the upper troposphere and the sign of the vorticity advection at 300 mb. Considering only the curvature of the contours, the advection term $(-V\,\partial\zeta/\partial s)_{300}$ is positive to the rear of a ridge and forward of a trough in the contour pattern. Fig. 7 shows the ratios of the percentages of observations of "Cirrus" to "No Cirrus" in relation to an idealised wave pattern in the 300 mb. flow. It is clearly seen that this ratio is a maximum in and to the rear of a ridge and a minimum in and to the rear of a trough. At first sight this does not appear fully consistent with the conclusion of Section 6, since we should expect upward vertical motion in the layer immediately below the tropopause to be taking place through the region forward of the trough line and to the rear of the ridge line at 300 mb. However, it is thought that although the air may commence to ascend immediately forward of the trough, some little time must elapse before the rising air becomes saturated, and hence before the appearance of cirrus clouds. Thus it is not surprising that the maximum frequency of reports should occur just in and to the rear of the ridge, as shown in Fig. 7.

8. Cirrus clouds in the stratosphere

Some 30 cases were reported when the bases or tops of cirrus cloud were above the tropopause obtained from analysis of neighbouring upper air ascents. In eight of these cases, the clouds had been definitely below the tropopause reported from neighbouring stations, and extended upwards above the tropopause. These cases are not surprising since local variations in the height of the tropopause could permit reported tops of cloud to extend above the tropopause height reported by the nearest radio-sonde ascent.

Some of the remaining reports were discussed by Jacobs (1954), who concluded that the extensive layer clouds observed over Southern England on 27 - 29th July, 1953 were in fact dust clouds, which originated from a volcanic eruption in Alaska on July 9th, 1953. The clouds reported in this case were estimated to be at heights in excess of 50,000 ft. at times.

It seems highly improbable that the remaining 18 cases could be attributed to similar disturbances, and in all probability these were genuine ice crystal cloud, at times as much as 10,000 ft. above the tropopause.

Little can be said concerning the existence of these very high clouds; the sample is too small to permit a statistical investigation, even if the relevant parameters were known at these heights. However, vorticity advection charts at 300 mb. were constructed for these occasions, and the results were remarkable in that for all cases of extensive cirrus sheets in the stratosphere, the sign of the advection of cyclonic vorticity at 300 mb. was negative (Table 13). The theory postulated by French and Johannessen associates upward vertical motion in the upper troposphere with a positive value of vorticity advection at 300 mb. assuming little or no vertical motion at the tropopause. A negative value of the vorticity advection would imply downward vertical motion below the tropopause, which would thus be a region of horizontal convergence. If this is so then it is possible that upward

/vertical

vertical motion was occurring in the lower stratosphere, and hence if the air were sufficiently moist at these levels the formation of cirrus cloud might result. Obviously, this is far from being anything but a tentative suggestion, and considerably more cases need to be reported of these high clouds which undoubtedly do exist in the stratosphere.

9. Conclusions

1. The observations confirm the work of earlier writers on the association of cirrus cloud in the troposphere with the area ahead of surface fronts, the high pressure side of the jet stream at 300 mb., and with thermal ridges. Considerable agreement is obtained with the statistical results presented by Murgatroyd and Goldsmith regarding the distribution of bases and tops of cirrus cloud in relation to the tropopause.

2. A strong association is found between the presence of cirrus cloud and the humidities at 500, 450 and 400 mb. Some assistance to the forecaster is possible in assessing the distribution of cirrus cloud from radio-sonde ascents if the humidities at all three levels are taken into consideration.

3. At all levels from 500 mb. to 300 mb. the winds between south and west were most frequently accompanied by cirrus cloud and winds between south and east had the lowest frequency of cirrus reports.

4. Consideration of the winds at 500 and 300 mb. confirms that cirrus cloud is associated with warm air advection at these levels. Also, cirrus cloud has an association with strong thermal contrasts as indicated by the 1000-500 mb. thickness pattern.

5. Cirrus cloud in the troposphere is associated with positive values of the advection of cyclonic vorticity at 300 mb., implying upward vertical motion in the upper troposphere.

6. Reports of cirrus cloud in the stratosphere were comparatively few, but are sufficient to confirm that high clouds at these levels do exist.

References

1. Murgatroyd, R. J. and P. Goldsmith. 1953. Meteorological Research Papers, Air Ministry, London. No. 833.

2. Kimachi, T. 1952. J. Met. Soc., Japan. Vol. 30, 9.

3. Bannon, J. K., R. Frith and H. C. Shellard. 1952. Geo.Mem. No. 88.

4. French, J. E. and K. R. Johannessen. 1953. Proc. Toronto Met. Conf.

5. Sawyer, J. S. and Betty Illett. 1951. Meteorological Research Papers, Air Ministry, London. No. 633.

6. Murray, R. 1953. Meteorological Research Papers, Air Ministry, London. No. 813.

7. Washington, A. W. S. T.R. 105/81. "The Cirrus Forecasting Problem".

8. Jacobs, L. 1954. Met. Mag., 83, pp. 115-119.

9. Crossley, A. F. 1954. Met. Mag., 83, pp. 66-73.

G.26866/PC/8/55/50

Table 1

Number of observations of "Cirrus" and "No Cirrus" at various distances from surface fronts

		Dist. ahead of front (x 10^2 mi.)			Dist. behind front (x 10^2 mi.)			No marked front	
		0-2	2-4	4-6	0-2	2-4	4-6		
Warm	Cirrus	33	21	8	13	2	1	Cirrus	38
	No Cirrus	2	7	8	0	3	3	No Cirrus	33
Cold	Cirrus	18	12	4	10	3	1		
	No Cirrus	6	3	0	6	2	0		
Occlusion									
	Cirrus	12	3	0	3	5	1		
	No Cirrus	0	5	1	1	3	2		

Table 2

Number of reports of "Cirrus" and "No Cirrus" at specified distances from features of the surface pressure chart

	Dist. from low or trough (x 10^2 mi.)				Dist. from ridge or high (x 10^2 mi.)				Totals
	0-2	2-4	4-6	>6	0-2	2-4	4-6	>6	
Cirrus	11	24	28	48	17	13	18	13	172
No Cirrus	4	8	3	18	9	12	4	11	69

Table 3

Dryness of air in association with reports of "Cirrus" and "No Cirrus". Parameter used is depression of dew point below temperature in °F

	500 mb.			450 mb.			400 mb.		
	Mean	No. of obs.	Sig^{ce}	Mean	No. of obs.	Sig^{ce}	Mean	No. of obs.	Sig^{ce}
Cirrus	18	164	Better than 0.1%	18	152	Better than 0.1%	17	156	Better than 0.1%
No Cirrus	26	80		26	74		25	72	

Table 4

Number of reports of "Cirrus" and "No Cirrus" when the depressions of frost points at 500, 450 and 400 mb. were simultaneously (a) less than the means for "Cirrus" reports (humidity favourable) and (b) greater than the means for "No Cirrus" reports (humidity unfavourable)

	Cirrus	No Cirrus	Totals
Humidity favourable	70	18	88
Humidity unfavourable	13	32	45
Totals	83	50	133

/Table 5

Table 5

Means in °F/1000 ft. of temperature lapse rate in 100 mb. intervals

	500 - 400 mb.	400 - 300 mb.	300 - 200 mb.
Cirrus	3.90	4.06	2.07
No Cirrus	4.02	4.02	1.47
"Student's 't'"	1.86	0.06	1.00

Table 6

Distribution of wind directions at various pressure levels for reports of "Cirrus" and "No Cirrus"

		N-NE	NE-E	E-SE	SE-S	S-SW	SW-W	W-NW	NW-N	Total	χ^2	Sig$^{ce.}$ (%)
500	Cirrus	17	11	6	5	19	30	40	19	147	23.3	0.3
	No Cirrus	11	5	7	2	8	8	13	12	66		
400	Cirrus	15	13	3	4	22	31	36	22	146	45.7	< 0.1
	No Cirrus	8	4	7	5	11	6	12	13	66		
300	Cirrus	17	13	2	7	14	35	29	26	143	24.0	0.1
	No Cirrus	7	6	4	4	11	11	10	14	68		
200	Cirrus	13	17	0	5	11	39	34	29	148	36.1	< 0.1
	No Cirrus	9	4	2	3	9	8	16	12	63		

Table 7

Number of occasions of cirrus associated with advection of warm or cold air

		Warm advection	Cold advection	Neither	χ^2	Significance
500-400 mb.	Cirrus	52	41	42	3.92	≏ 20%
	No Cirrus	20	23	22		
400-300 mb.	Cirrus	53	31	48	13.67	≏ 0.1%
	No Cirrus	20	26	21		
300-200 mb.	Cirrus	50	42	42	15.46	< 0.1%
	No Cirrus	16	30	18		
500-300 mb.	Cirrus	70	37	35	21.40	< 0.1%
	No Cirrus	23	30	14		

Table 8

Association of cirrus with the thermal wind speed

	Cirrus	No Cirrus
Mean thermal wind (kt.)	21	16
No. of obs.	174	79
Std. deviation	11.4	12.3
Std. error of mean	0.9	1.4

/Table 9

Table 9

Association of cirrus with curvature of thickness lines

(No. of cases)

	Cyclonic	Anticyclonic	Neither	Totals
Cirrus	59	54	49	162
No Cirrus	31	15	35	81

Table 10

Association of cirrus with sign of vorticity advection at 300 mb. for points at 100 mi. intervals along aircraft track

Sign of advection
(No. of cases)

Cirrus	+	-	0	Total
Thick	23	7	0	30
Patchy	18	16	0	34
Nil	19	39	3	61

Table 11

Association of cirrus with sign of vorticity advection at 300 mb. for spot reports

Sign of advection
(No. of cases)

Cirrus	+	-	0	Total
Thick	69	19	3	91
Patchy	27	28	5	60
Nil	18	40	2	60

Table 12

Sign of vorticity advection at 300 mb. combining Tables 10 and 11

Sign of advection
(No. of cases)

Cirrus	+	-	0	Total
Thick	92	26	3	121
Patchy	45	44	5	94
Nil	37	79	5	121

Table 13

Sign of vorticity advection at 300 mb. for cirrus cloud certainly in the stratosphere (Route flights and spot observations included)

Sign of advection
(No. of cases)

Cirrus	+	-	0	Total obs.
Thick	0	17	1	18
Patchy	3	5	0	8

DISTRIBUTION OF CIRRUS TOPS BELOW THE TROPOPAUSE

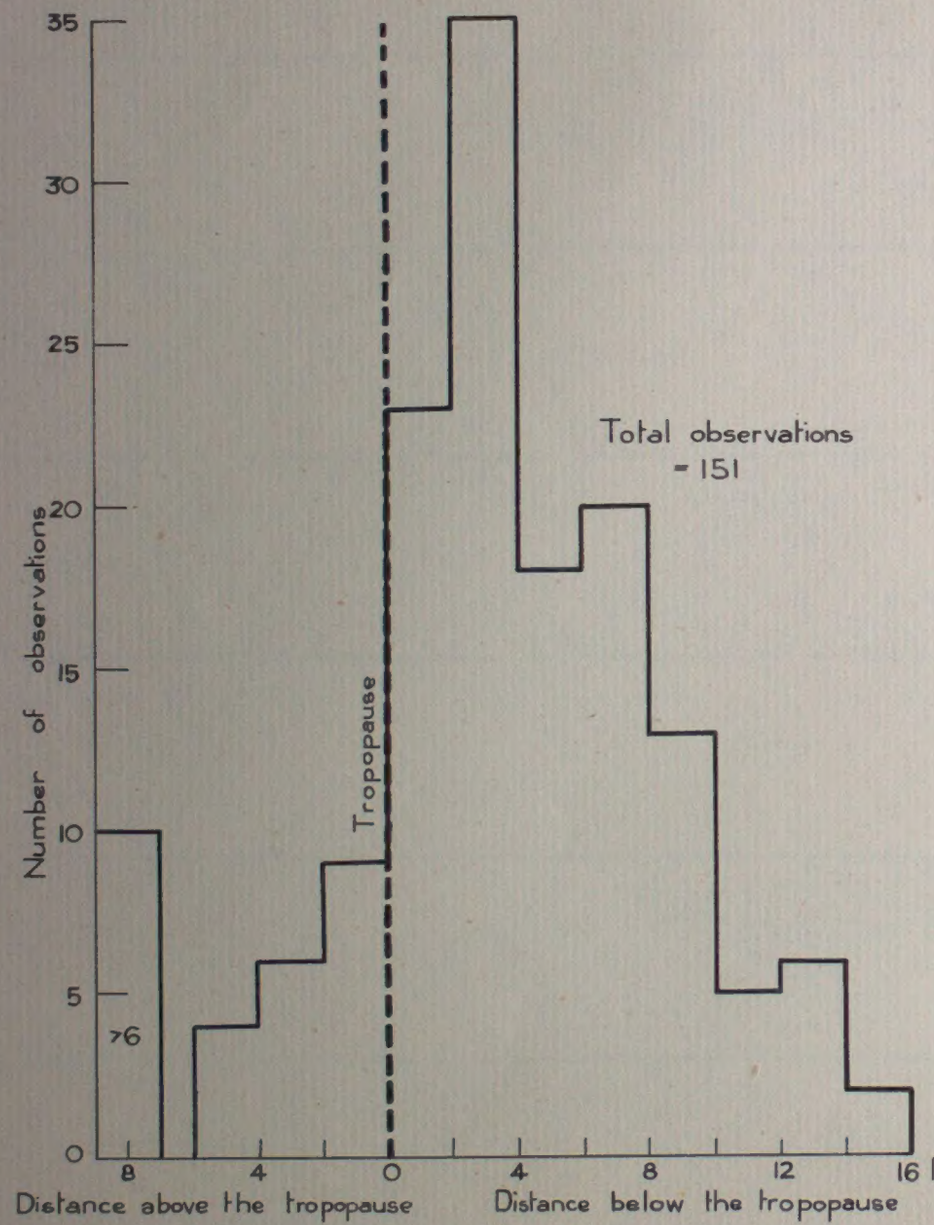

Fig. 1

DISTRIBUTION OF CIRRUS BASES BELOW THE TROPOPAUSE

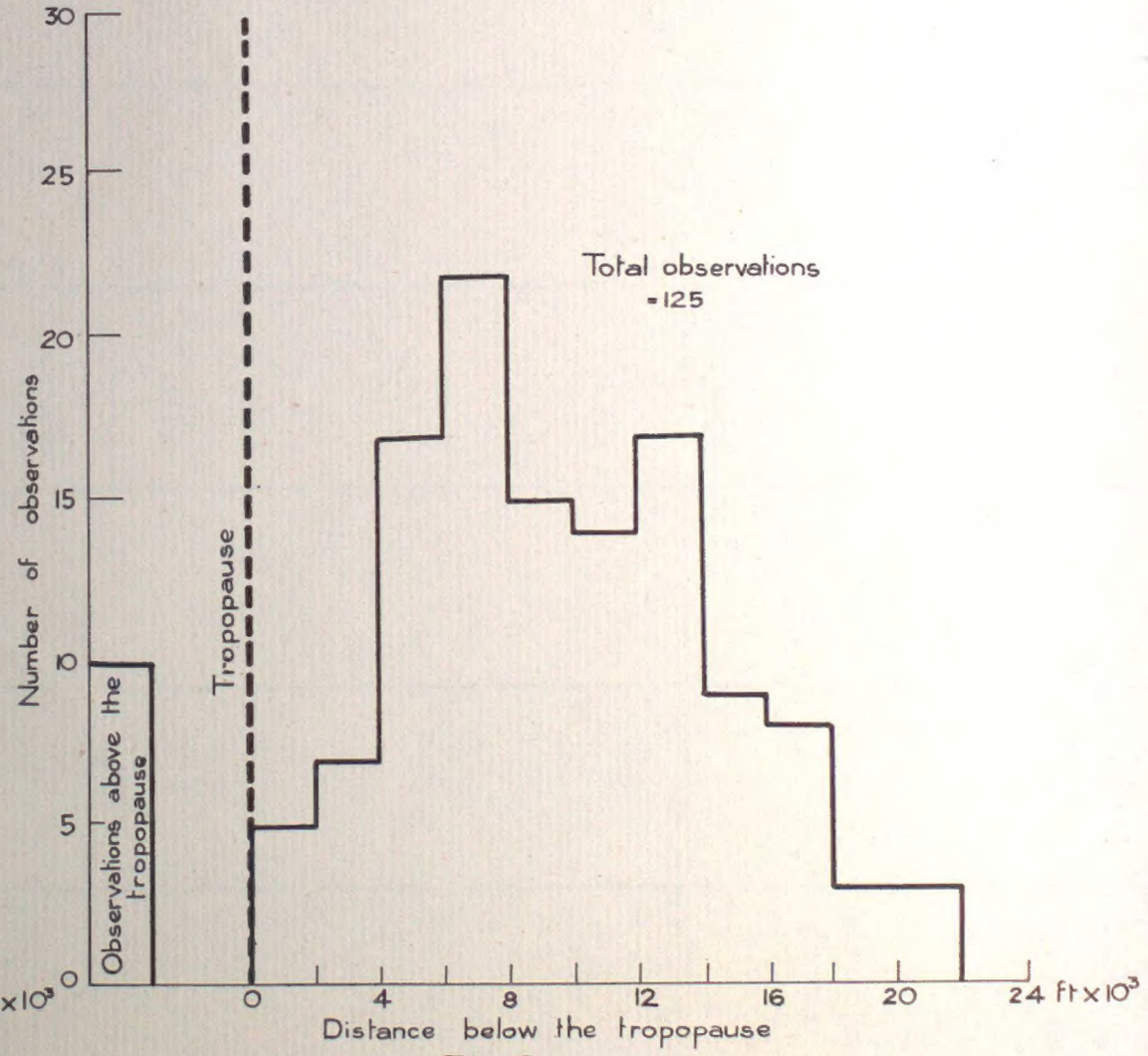

Fig. 2

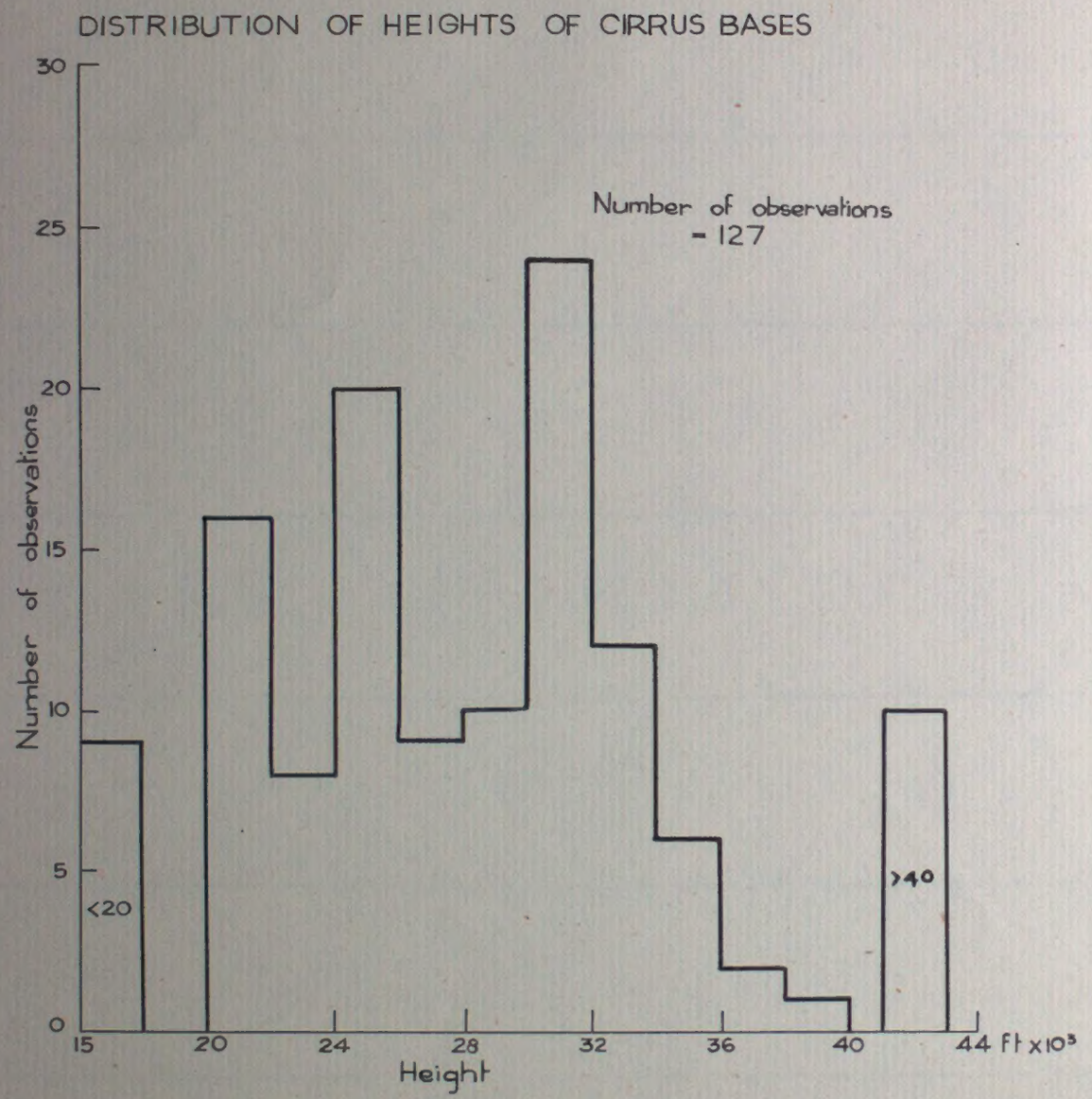
DISTRIBUTION OF HEIGHTS OF CIRRUS BASES
Number of observations
= 127
Number of observations
<20
>40
0
5
10
15
20
25
30
15
20
24
28
32
36
40
44 ft x10³
Height

Fig. 3

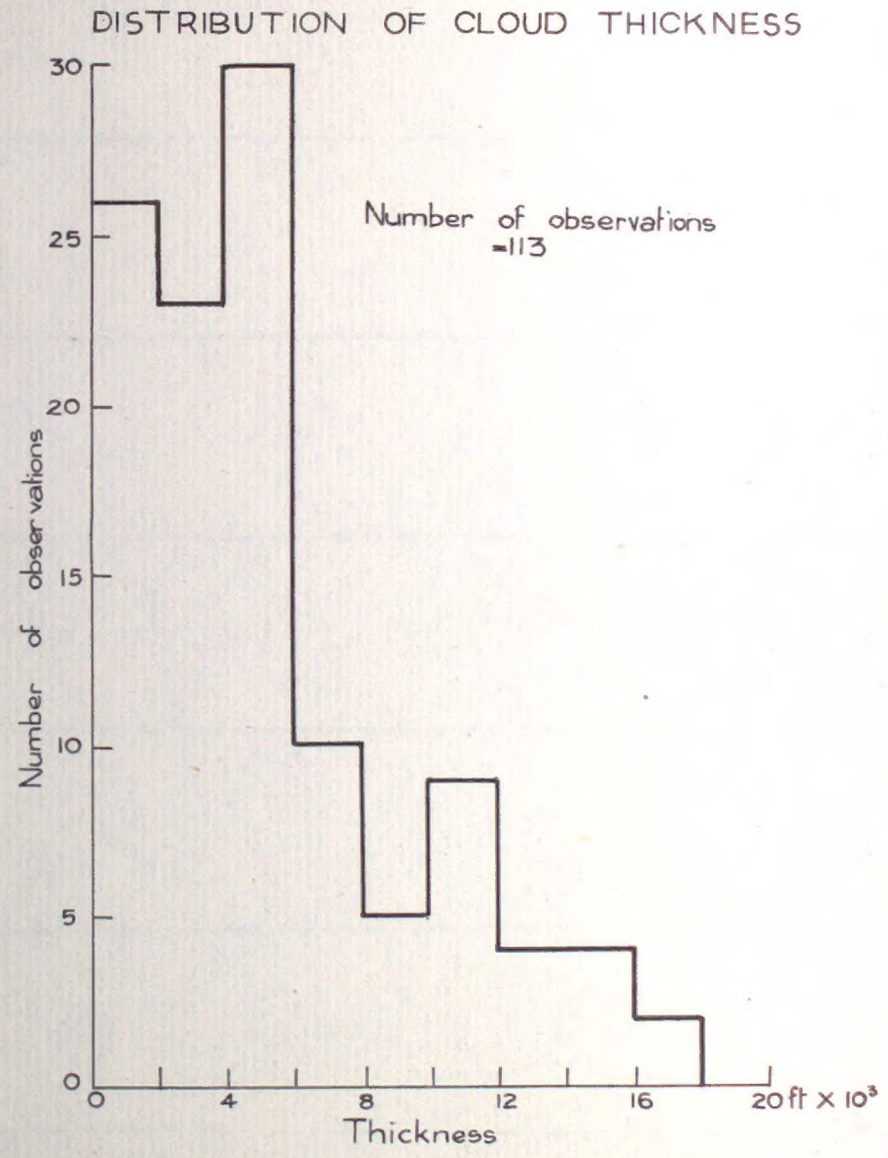
DISTRIBUTION OF CLOUD THICKNESS
Number of observations
=113
Number of observations
0
5
10
15
20
25
30
0
4
8
12
16
20 ft x 10³
Thickness

Fig. 4

Ratios of the percentages of number of observations of "cirrus" to "no cirrus" in relation to an assumed wave-form in the total thickness pattern.

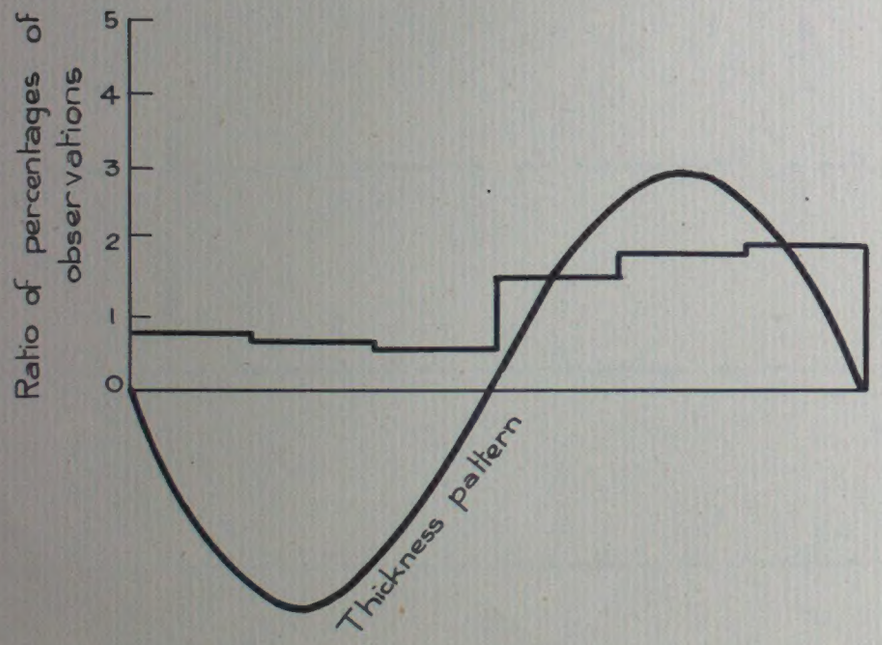

Fig. 5

Ratios of the percentages of number of observations of cirrus" to "no cirrus" in relation to an assumed wave-form in 300mb. contour pattern

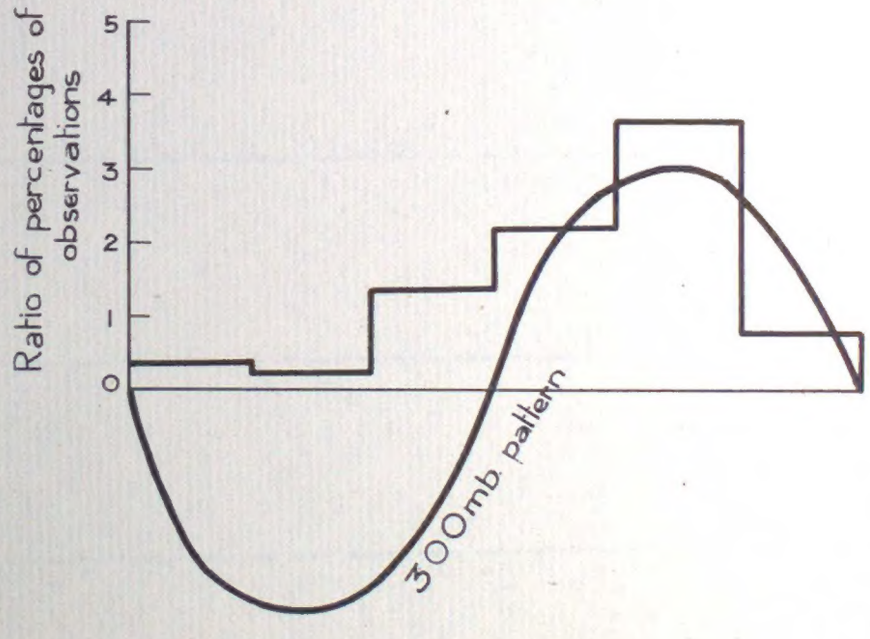

Fig. 7

FREQUENCY OF REPORTS IN RELATION TO DISTANCES FROM AXIS OF JET STREAM AT 300 mb.

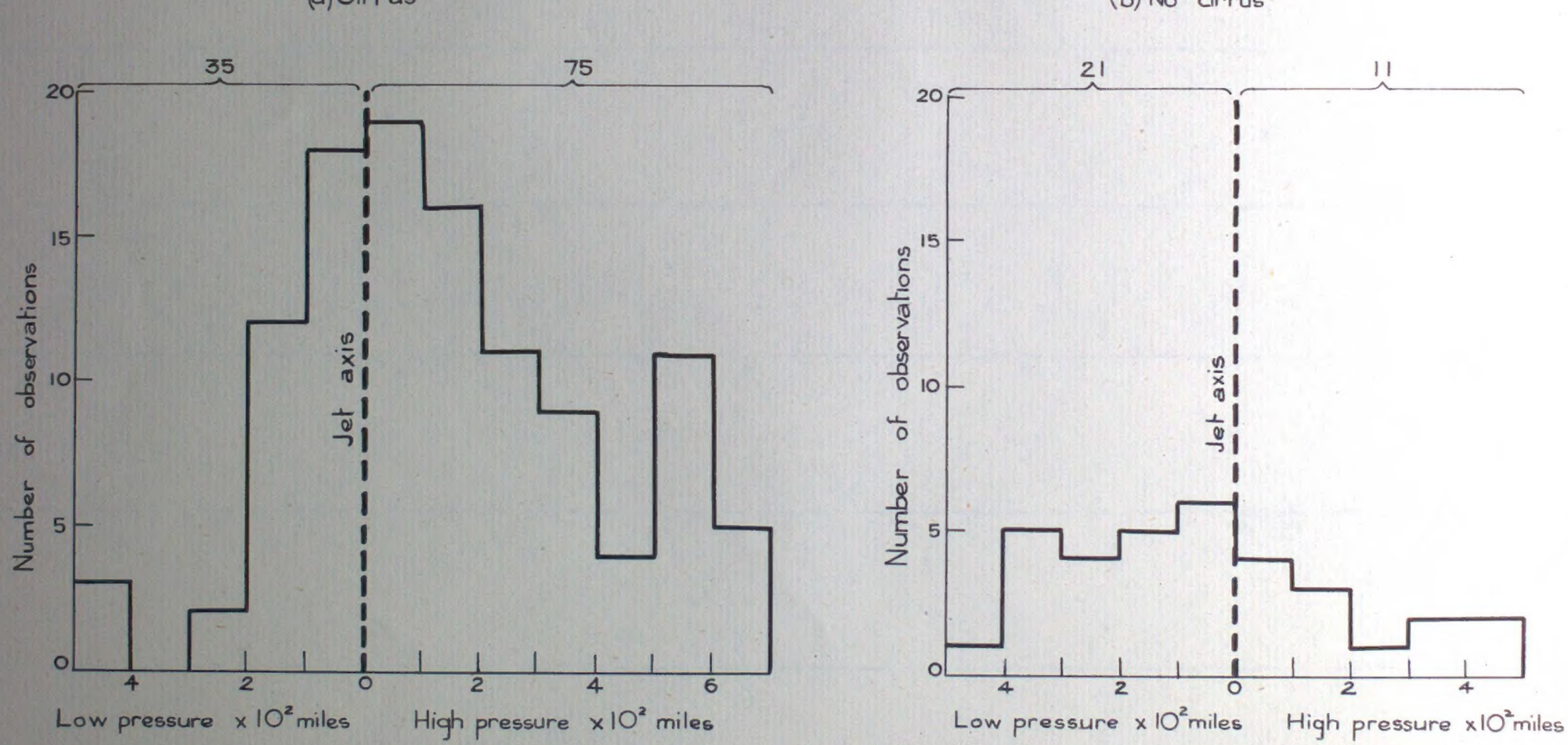

Fig. 6